Turkish Journal of Electrical Engineering & Computer Sciences
http://journals.tubitak.gov.tr/elektrik/
Research Article

Turk J Elec Eng & Comp Sci
(2020) 28: 3183 – 3192

doi:10.3906/elk-2002-113

SDMA-based Distributed Device Discovery for D2D communication

Muddasir RAHIM, Muhammad Awais JAVED*, Ahmad Naseem ALVI
Department of Electrical and Computer Engineering, COMSATS University Islamabad, Islamabad, Pakistan

Received: 17.02.2020 • **Accepted/Published Online:** 13.06.2020 • **Final Version:** 30.11.2020

Abstract: Device-to-device (D2D) communication is an important technique to improve capacity of future wireless networks. Cellular communications, internet of things and intelligent transport systems are key areas that could benefit from reduced end-to-end delay provided by D2D communication. Efficient device discovery is an important precondition to enable D2D communication. In this paper, we propose a space division multiple access (SDMA)-based distributed device discovery protocol in which user equipments (UEs) periodically transmit discovery beacons to each other. The proposed protocol reduces contention in the discovery beacons by allocating resource blocks to the UEs based on their location. Simulations results show that the proposed protocol improves discovery rate and discovery delay in a dense network.

Key words: Device-to-device communication, device discovery, space division multiple access

1. Introduction

Recent growth of wireless communication has increased the demand of radio frequency spectrum, which however is a limited resource. To deal with the challenge of already congested frequency spectrum, there are two possible solutions: i) either reduce the existing cellular cell size and add more network resources [1], which is an expensive solution, or ii) use device-to-device (D2D) communication [2]. D2D communication enables direct communication among the mobile devices which are in each other's transmission range without the involvement of base station (BS).

The possible use cases of D2D communication include vehicular information exchange, emergency data dissemination and location aware services in smart cities [3, 4]. As an example, vehicular networks can utilize D2D communication to quickly communicate with the nearby vehicles. Particularly, in emergency situations, this can deliver faster notification to vehicles. Moreover, periodic safety messages that need to be exchanged between nearby vehicles in a vehicular network, can also be efficiently transmitted without going through the base station [5].

To realize D2D communication, several challenging issues such as device discovery, spectrum resource allocation, interference management, power control, and communication security, have to be solved [6]. Among these issues, the first prerequisite for implementing D2D communication is the device discovery. It enables devices to discover potential D2D candidates in the proximity and establish a direct connection with them. To accomplish this task, devices share number of messages between the user equipments (UEs), and between the UEs and the BS. These messages gather information such as device location, channel quality, and device identity number etc.

*Correspondence: awais.javed@comsats.edu.pk

Device discovery in D2D communication is categorized into two types: network assisted device discovery and distributed device discovery. In network assisted device discovery, BS is directly involved in the device discovery process and UEs that intend to start D2D communication send discovery requests to the BS [7]. In turn, BS checks the availability and communication feasibility with the intended D2D receivers and sends this information back to the UE that initiated the discovery request. A drawback of network assisted discovery is that the workload of BS is increased which may negatively impact other tasks carried out by the BS [8–10].

In distributed device discovery, the UEs exchange messages with each other for discovery process without the involvement of BS. Devices may either periodically share discovery messages with each other or send them on-demand. Distributed discovery reduces the load on the BS, but it needs efficient medium access protocol to avoid contention between discovery messages shared by UEs.

Distributed device discovery protocols such as [11] allow UEs to share periodic discovery beacons with each other using carrier sense multiple access with collision avoidance (CSMA/CA) in a small dedicated set of resource blocks called discovery zone resource block set (allocated for discovery process). However, the proposed protocol suffers from contention and packet loss especially in dense network.

In this paper, we propose a space division multiple access (SDMA)-based protocol for distributed discovery. To overcome the problem of contention by using CSMA/CA in dense networks, we propose to divide the cell into different regions and allocate separate resource blocks to each region (while keeping the discovery zone resource block set fixed). Simulation results show that our proposed protocol can reduce contention in the discovery beacons and improve device discovery rate.

The rest of paper is organized as follows: In Section 2, we discuss the resent work related to device discovery in D2D communication. Section 3 explains the SDMA-based distributed device discovery protocol. In Section 4, we discuss the simulation scenario and performance evaluation results. Finally, conclusions are presented in Section 5.

2. Related works

In this section, we present a review of the recent work in device discovery in D2D communication. Authors in [12] design a peer discovery protocol using social awareness information. Social parameters such as contact duration, contact interval and centrality is used to divide UEs into different groups. Those groups that have a high centrality are allocated more transmit power since they can send beacons to more number of UEs.

The work in [13] proposes a duplex mode switching algorithm to improve the collisions in the device discovery messages. In case the signal to noise ratio falls below a threshold, the D2D users change their transmission mode from half-duplex to full-duplex. Moreover, a power control mechanism is also implemented to improve energy efficiency of the device discovery process.

In [14], authors propose a hybrid D2D discovery method where the cellular network evaluates the feasibility of a UE pair to establish a D2D link. If the two D2D UEs are within each other's transmission range, the eNodeB informs the UEs to initiate D2D communication. However, if the two UEs are far away, they resort to cellular communication.

Authors in [15] propose a discovery scheme where neighboring UEs detect potential D2D partners by monitoring sounding reference signal (SRS) during uplink transmission. Each UE listens to the SRS channel periodically to discover other UEs with a high signal to noise ratio and also develop a framework to estimate the channel statistics.

End-user communications devices also known as UEs are carried by subscribers that commute between different places throughout the day, which induce a specific time-dependent patterns of daily UE density within each base station. In [16], authors propose a performance analysis for D2D discovery for multiple periods and show the impact of both high and low transmitting users density cases. The analysis showed that the discovery retransmission scheme behaves better at low transmit UE density while probability-based transmission scheme behaves better at high density.

In [17], authors performed an analytical study of the number of UEs in a network assisted D2D discovery group. This paper analyze the statistical behavior of the distance between two D2D peers using the core network knowledge, assuming that the base stations (BS) follow a Poisson distribution. Based on this assumption, the authors identify conditions to maximize the D2D discovery probability.

Authors in [18] evaluate the impact of UE density and traffic load on a proposed transmission scheduling scheme. The model is first evaluated in a static network by using different levels of user densities, then it is evaluated in a dynamic networks use-case by introducing a realistic human mobility model.

In [19] authors proposed a new proximity beacon-based peer discovery scheme with a low power consumption. The key idea of the scheme was to use spatial correlation of the wireless channel and the trade-off between the power consumption and the accuracy of the peer detection.

Authors in [20] proposed an adaptive algorithm for device discovery in D2D communication which improves the discovery process in dynamic environments. The proposed adaptive algorithm works on the instantaneous density prediction results obtained using support vector regression (SVR). The algorithm is first trained with real network traces. A key advantage of using SVR is that it requires minimal computational resources, unlike other regression tools, such as artificial neural networks (ANN) which consume more processing time, need more complex configuration, and suffer from lack of generality causing under/over fitting issues.

D2D discovery scheme based on random backoff is proposed in [11] in which D2D UEs are allocated set of resource blocks for sending discovery beacons. The set of resource blocks are repeated after a certain time period. UEs periodically transmit discovery beacons to neighboring UEs. As a result, each UE keeps a neighbor table of active D2D users and use this information before transmitting D2D messages. Within each resource block set, UEs use CSMA/CA to pick a single resource block for transmission of discovery beacons. Those UEs which fail to transmit their discovery beacons at first attempt randomly pick another resource block within same resource block set. UEs which still do not succeed in transmission of discovery beacons in their allocated resource block set attempt transmission in the next resource block set.

As compared to the existing work in the literature, our work is focused on improving the reliability and accuracy of distributed device discovery while efficiently utilizing the resource blocks. The major contributions of this paper are as follows.

- We propose a SDMA-based device discovery protocol that reduces the contention problem of CSMA/CA based distributed device discovery.

- The proposed SDMA-based device discovery protocol uses an efficient resource allocation scheme that improves the discovery rate and discovery delay of UEs while using the same number of resource blocks as required by CSMA/CA based technique [11].

3. SDMA-based distributed device discovery protocol

3.1. System model

We consider the scenario similar to the work in [11] where UEs are uniformaly distributed in a cell as shown in Figure 1. UEs communicate with each other using D2D links and use distributed device discovery procedure. For this purpose, discovery zone resource block sets are allocated to send discovery beacons. As shown in Figure 2, two discovery zone resource block sets are shown each having R resource blocks. The total duration of discovery zone resource block set is T_{DZ} whereas the time between the two consecutive discovery zone resource block sets is T_d. UEs periodically transmit discovery beacons containing information about their location to the neighboring UEs.

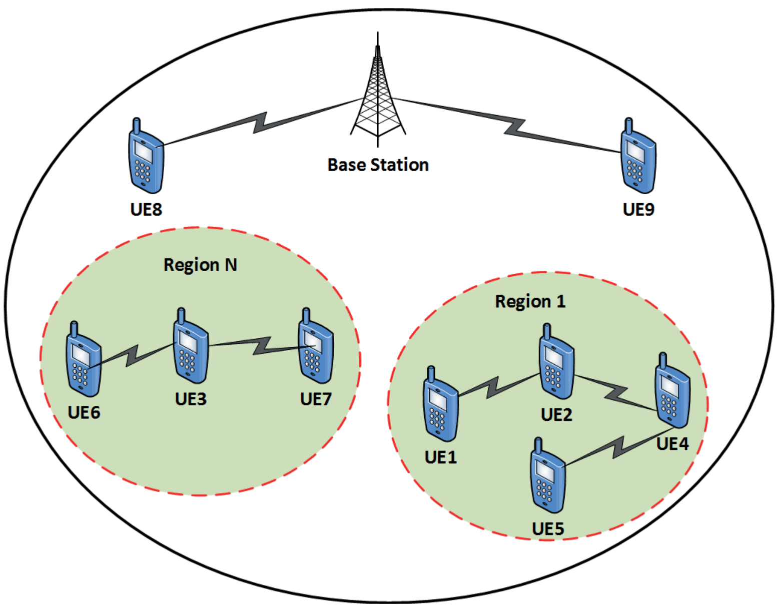

Figure 1. System model consisting of a cell with UEs divided in different regions.

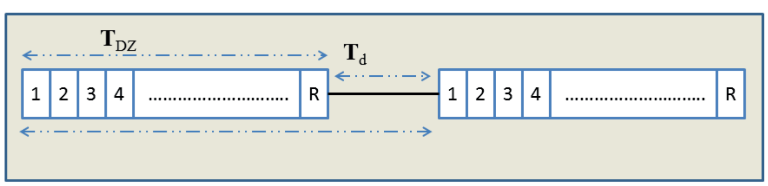

Figure 2. Discovery zone resource block sets, here T_{DZ} is the total duration of discovery zone resource block set and T_d is the time between the two consecutive discovery zone resource block sets.

3.2. Working of the proposed algorithm

We divide the cell into N regions as shown in Figure 1. Furthermore, we also divide a single discovery zone resource block set into N smaller regional resource block sets as shown in Figure 3. Based on location, each UE marks itself as member of one of the regions. We assume that all UEs generate their discovery beacons randomly within K discovery zone resource block sets. This means that if there are M nodes in the cell, every discovery zone resource block set has on average $\frac{M}{K}$ UEs generating discovery beacons.

The proposed protocol uses space division multiple access technique to allocate resource blocks to UEs within a single discovery zone resource block set. A UE belonging to region 1 is allocated the first regional resource block set R_1 and so on e.g., UE1 and UE2 are located in the first region, so they use the resource blocks allocated for the first region, UE4 in the second region uses the resource blocks of the second region. Similarly, UE3 and UE5 are located in region N and use the resource blocks of the Nth region as shown in Figure 3. Within a regional resource block set, UEs use CSMA/CA to transmit their discovery beacons.

In comparison, the work in [11] allocates resource blocks to all UEs within a discovery zone resource block set as shown in Figure 4. As a result, there are more chances of collision and CSMA/CA fails to coordinate channel access particularly in a dense network. Our proposed protocol uses SDMA on top of CSMA/CA to reduce contention and improve the transmission probability.

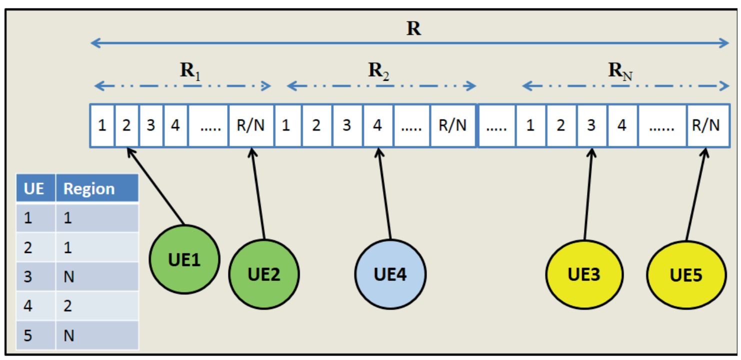

Figure 3. Resource block allocation in SDMA based device discovery where UEs are allocated resources based on their location, here R resource blocks are divided into N regional resource block sets.

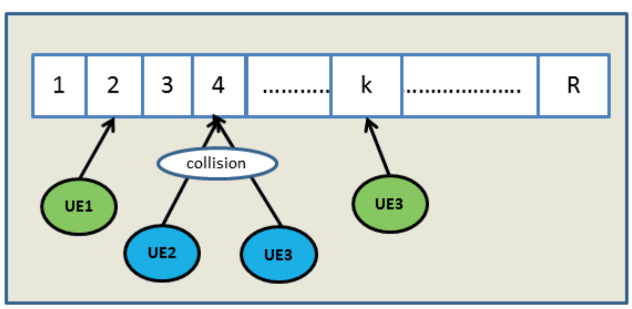

Figure 4. Resource block allocation using random backoff where resources are allocated to all UEs using CSMA/CA.

The algorithm of the proposed protocol is shown in Algorithm 1. At the start of each discovery zone resource block set, each UE maps itself to a particular region. If a UE has discovery beacon to generate in the current discovery zone resource block set, it finds its regional resource block set number. Then, at the start time of its regional resource block set, UE takes a random backoff within the range $[0, W]$ where W is the maximum size of contention window. If the discovery beacon is not successfully transmitted, UE repeats the backoff process and transmits again unless the packet is transmitted or maximum number of allowed retransmissions are over. If the backoff value taken is such that it exceeds the number of remaining resource blocks in the current regional resource block set, UE keeps the discovery beacon in its queue and attempts transmission at the start of next regional resource block set.

Algorithm 1: Proposed SDMA-based device discovery protocol

Data: Input
Number of nodes M;
Number of resource blocks in discovery zone resource block set R ;
Number of regions N;
Maximum contention window size W;
for *start time of each discovery zone resource block set* **do**
    for *all vehicles* v *with a discovery beacon to send* **do**
        Map vehicle v to a region based on its location $v \rightarrow N_v$
        Find its regional resource block set number R_N;
        At the start time of R_N, take backoff within a range $[0, W]$ and use CSMA/CA to transmit;
        If a simultaneous transmission is detected, repeat the backoff process for transmission;
        If the backoff value is greater than the remaining resource blocks in the current regional resource block set, keep the discovery beacon in the queue and transmit in the next discovery zone resource block set.
    end
end

4. Performance evaluation

In this section, we present the simulation based performance analysis of the proposed SDMAD protocol and compare results with the RBD protocol from the literature:

SDMAD: We propose a space division multiple access (SDMA)-based protocol for distributed discovery (SDMAD). To overcome the problem of contention by using CSMA/CA in dense networks, we propose to divide the cell into different regions and allocate separate resource blocks to each region.

RBD: Authors in [11] proposed the random backoff discovery (RBD) protocol in which D2D UEs are allocated set of resource blocks for sending discovery beacons. These resource blocks are repeated after a certain time period. UEs periodically transmit discovery beacons to neighboring UEs using random contention process.

The UEs are randomly deployed with in the cell of radius 500 m as shown in Figure 5. The SDMAD protocol is implemented in MATLAB and Monte Carlo based simulation is performed to evaluate the performance metrics and results are obtained by averaging 10^6 experiments. Simulation parameters are listed in the Table.

Table . Parameters used in simulation.

Parameters	Values
Total number of D2D users, M	$50 - 300$
Number of discovery zone resource block sets, K	20
Number of resource blocks in a resource block set, R	52
Time between two consecutive discovery zone resource block sets, T_d	10 s
Duration of discovery zone resource block set, T_{DZ}	52 ms
Maximum size of contention window, W	6

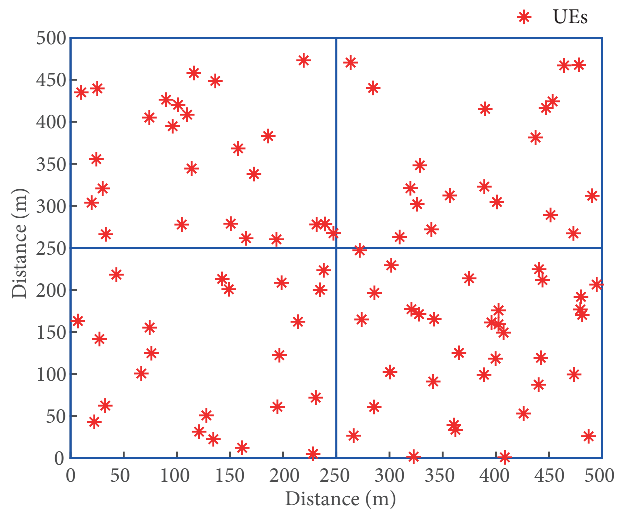

Figure 5. Simulation scenario in MATLAB showing random deployment of UEs in a cell.

We used the following three performance metrics in this section.

- **Number of collisions:** It is defined as the total number of resource blocks which were chosen by two or more UEs to transmit a discovery beacon and hence resulted in a collision.
- **Discovery rate:** It is defined as the ratio of the total number of discovery beacons that are successfully transmitted without collisions to the total number of discovery beacons generated by the UEs.
- **Discovery delay:** It is defined as the difference between the time when the discovery beacon was generated and the time when the discovery beacon was transmitted.

Figure 6 shows the number of collisions for the two protocols against different number of UEs in the cell. It can be seen that the proposed SDMAD protocol results in less than 100 collisions at the highest number of UEs value i.e. 300. On the contrary, RBD protocol causes large number of collisions as the number of UEs are increased above 150. Out of total $R \times K = 52 \times 20 = 1040$ resource blocks, around 1000 resource blocks result in collisions for the RBD protcol when the number of UEs are 300. As the number of UEs which cannot transmit in a discovery zone resource block set grow, more discovery beacons remain in the queue for retransmissions. This over crowds the next discovery zone resource block sets and cause more UEs to contend resulting in more collisions. SDMAD protocol efficiently reduces these collisions by using regional resource block sets and reducing the number of UEs which are not able to transmit in a discovery zone resource block set.

Figure 7 shows the discovery rate of the two protocols at different number of nodes. It can be seen that for small number of nodes SDMAD and RBD protocols show a similar discovery rate of higher than 0.98. However, unlike the RBD protocol, the SDMAD protocol also maintains a discovery rate of higher than 0.8 for different UE density in the cell. Particularly, when the number of UEs are 300, SDMAD protocol has 8 times higher discovery rate than the RBD protocol. This gain is achieved due to allocating separate regional resource block sets to UEs based on their location. Since, in a single discovery zone resource block set, not all UEs from the same region generate discovery beacons, our proposed SDMAD protocol reduces contention. Note that once discovery beacons are not transmitted in a discovery zone resource block set, they are kept in the queue and transmitted again in the next discovery zone resource block set. Thus, the next discovery zone resource block set gets more crowded and result in further collisions and so on. This is one major reason of such a low discovery rate for RBD protocol.

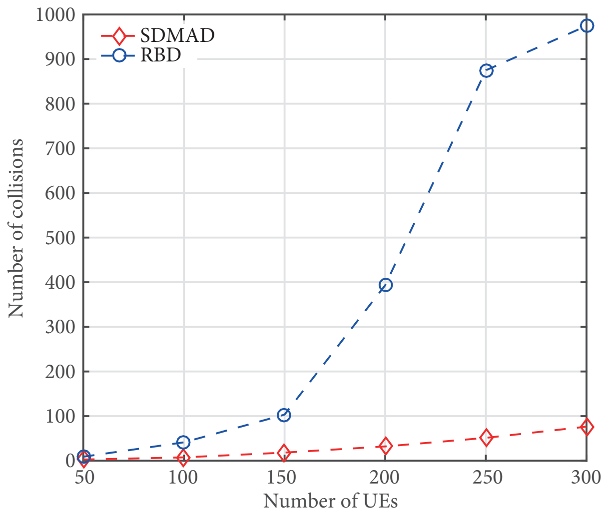

Figure 6. Number of collisions for SDMAD and RBD at different number of UEs.

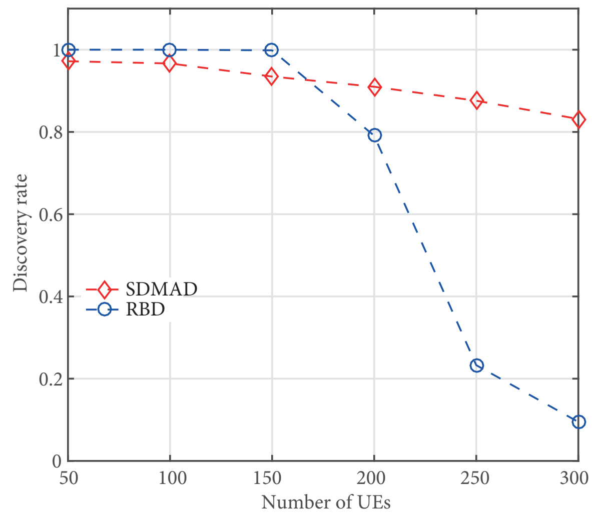

Figure 7. Discovery rate for SDMAD and RBD at different number of UEs.

Figure 8 presents the discovery delay for the two protocols as the number of UEs are increased. The proposed SDMAD shows a discovery delay of lower than 0.6 s even when the number of UEs are increased to 300. On the other hand, RBD protocol shows a significant increase in discovery delay as the number of UEs in the cell goes above 150, reaching up to 1.9 s at the highest number of nodes. This increase in RBD protocol can be explained due to large number of collisions which cause frequent retransmissions and discovery beacons to be stored in queue till the next discovery zone resource block set. On the other hand, SDMAD reduces the number of collisions which improve the discovery delay.

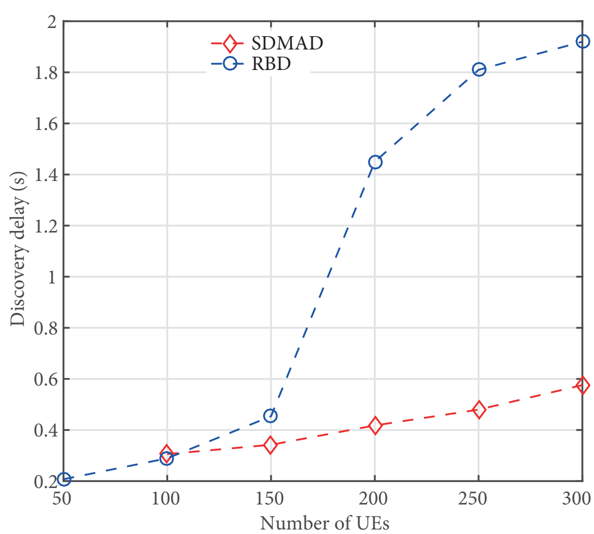

Figure 8. Discovery delay for SDMAD and RBD at different number of UEs.

5. Conclusion

In this paper, we propose a SDMA-based distribute device discovery protocol that uses SDMA on top of CSMA/CA to effectively transmit discovery beacons. Based on location, UEs map themselves into different regions and each region gets allocated a different set of resource blocks. Simulation results show that the proposed protocol effectively reduces collisions and improves the discovery rate of UEs up to 8 times as compared to the random backoff discovery technique. Moreover, the proposed protocol reduces discovery delay by 70%.

References

[1] Meshkova E, Riihijärvi J, Petrova M, Mähönen P. A survey on resource discovery mechanisms, peer-to-peer and service discovery frameworks. Computer Networks 2008; 52 (11): 2097-2128.

[2] Jameel F, Hamid Z, Jabeen F, Zeadally S, Javed MA. A survey of device-to-device communications: research issues and challenges. IEEE Communications Surveys & Tutorials 2018; 20 (3): 2133-2168.

[3] Tang H, Ding Z. Mixed Mode transmission and resource allocation for d2d communication. IEEE Transactions on Wireless Communications 2016; 15 (1): 162-175.

[4] Liu Z, Xie Y, Chan KY, Ma K, Guan X. Chance-constrained optimization in d2d-based vehicular communication network. IEEE Transactions on Vehicular Technology 2019; 68 (5): 5045-5058.

[5] Huang J, Liao Y, Xing C, Chang Z. Multi-hop d2d communications with network coding: from a performance perspective. IEEE Transactions on Vehicular Technology 2019; 68 (3): 2270-2282.

[6] Jameel F, Javed MA. On the performance of cooperative vehicular networks under antenna correlation at RSU. AEU - International Journal of Electronics and Communications 2018; 95: 216-225.

[7] Mumtaz S, Rodriguez J. Smart Device to Smart Device Communication. Cham, Switzerland: Springer International Publishing, 2014.

[8] Liu J, Kawamoto Y, Nishiyama H, Kato N, Kadowaki N. Device-to-device communications achieve efficient load balancing in LTE-advanced networks. IEEE Wireless Communications 2014; 21 (2): 57-65.

[9] Sudip M, Khatua M. Semi-distributed backoff: collision-aware migration from random to deterministic backoff. IEEE Transactions on Mobile Computing 2014; 14 (5): 1071-1084.

[10] Soojung J, Chang S. A discovery scheme for device-to-device communications in synchronous distributed networks. In: The 16th International Conference on Advanced Communication Technology; Pyeongchang, South Korea; 2014. pp. 815-819.

[11] Zhang J, Deng L, Li X, Zhou Y, Liang Y et al. Novel device-to-device discovery scheme based on random backoff in LTE-advanced networks. IEEE Transactions on Vehicular Technology 2017; 66 (12): 11404-11408.

[12] Zhang B, Li Y, Jin D, Hui P, Han Z. Social-aware peer discovery for d2d communications underlaying cellular networks. IEEE Transactions on Wireless Communications 2014; 14 (5): 2426-2439.

[13] Kaleem Z, Qadri NN, Duong TQ, Karagiannidis GK. Energy-efficient device discovery in d2d cellular networks for public safety scenario. IEEE Systems Journal 2019; 13 (3): 2716-2719.

[14] Mingfu L,Tsai H. Design and evaluation of a hybrid d2d discovery mechanism in 5G cellular networks. In: The 10th International Conference on Ubiquitous and Future Networks (ICUFN); Prague, Czech Republic; 2018. pp. 641-643.

[15] Huan T, Ding Z, Levy BC. Enabling d2d communications through neighbor discovery in LTE cellular networks. IEEE Transactions on Signal Processing 2014; 62 (19): 5157-5170.

[16] Dong L, Liu Y. Performance analysis for LTE-A device-to-device discovery. In: IEEE 26th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC); Hong Kong, China; 2015. pp. 1531-1535.

[17] Xenakis D, Kountouris M, Merakos L, Passas N, Verikoukis C. Performance analysis of network-assisted d2d discovery in random spatial networks. IEEE Transactions on Wireless Communications 2016; 15 (8): 5695-5707.

[18] Gao C, Li Y, Fu H, Niu Y, Jin D et al. Evaluating the impact of user behavior on d2d communications in millimeter-wave small cells. IEEE Transactions on Vehicular Technology 2016; 66 (7): 6362-6377.

[19] Woongsup L, Kim J, Choi S. New D2D peer discovery scheme based on spatial correlation of wireless channel. IEEE Transactions on Vehicular Technology 2016; 65 (12): 10120-10125.

[20] Mosbah AB, Hammami SE, Moungla H, Afifi H, Kamal AE. Enhancing device-to-device direct discovery based on predicted user density patterns. Computer Networks 2019; 151: 245-259.